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Theory of Spin Wave Emission from a Bloch Domain Wall

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Abstract. An analytical theory of exchange spin wave emission from a Bloch domain wall in a thin film is presented. We model a ferromagnet with antiparallel domains aligned along the (in-plane) easy-axis, where the hard axis points out of the film plane. When excited by a continuous, harmonic external magnetic field oriented orthogonal to the domain wall, plane spin waves are emitted above a threshold frequency. The precession is elliptical, with the ellipticity reducing with increasing wavevector.

Introduction

Exchange spin waves (SWs) have great potential as **information carriers** on the nanoscale, due to their **short wavelengths** and **isotropic, quadratic dispersion** [1-2].

The wavelengths of SWs generated via **electrical antennas** or point contacts are **limited** by the **size** of the device [2].

Recent experimental [3,4], modelling [5] and numerical [6] work has demonstrated that **domain walls can generate SWs**.

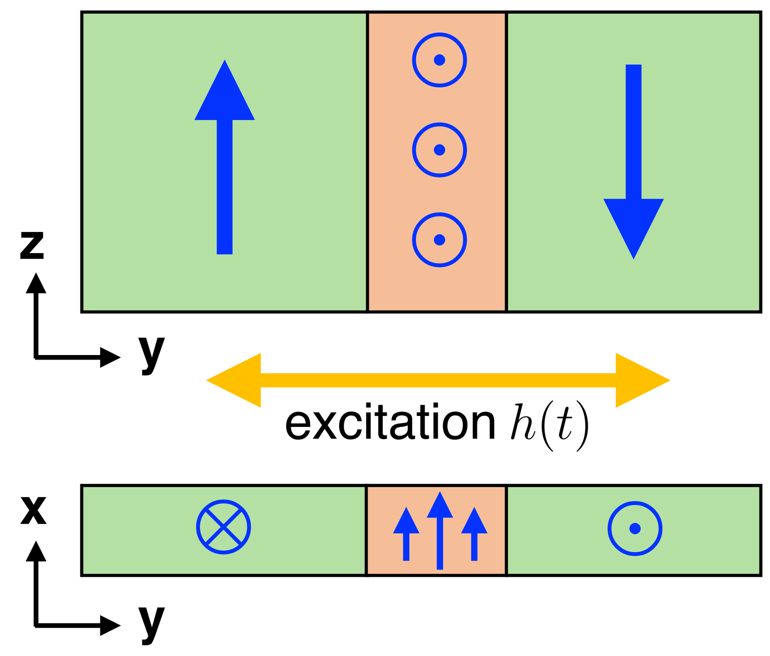


Fig.1: Model of the single layer system: **a)** top and **b)** side view.

We use **analytical theory** to explain this phenomena for **exchange SWs**.

We model an infinitely wide **thin film**, with a **pinned Bloch domain wall** separating two antiparallel domains, shown in Fig.1. Note the film lies in the **y-z plane**.

Background Theory

Excitation of the sample via an in-plane, time-varying magnetic field $\mathbf{h}(t)$ induces **precession** of the magnetisation $\mathbf{M}$, described by the **Landau-Lifshitz equation** without damping:

$$\frac{\partial \mathbf{M}}{\partial t} = -\gamma[\mathbf{M} \times \mathbf{H}_{eff}]$$

The effective field $\mathbf{H}_{eff}$ is the functional derivative of the free energy density W:

$$W = \underbrace{\frac{1}{2}\alpha\left(\frac{\partial \mathbf{M}^2}{\partial y^2}\right)}_{\textit{Exchange}} - \underbrace{\frac{1}{2}\beta_{\parallel}(\mathbf{M}\cdot\hat{\mathbf{n}}_{\parallel})^2}_{\textit{In-Plane Anisotropy}} + \underbrace{\frac{1}{2}\beta_{\perp}(\mathbf{M}\cdot\hat{\mathbf{n}}_{\perp})^2}_{\textit{Out-of-Plane Anisotropy}} - \underbrace{\mathbf{h}(t)\cdot\mathbf{M}}_{\textit{Excitation}}$$

Minimising W in spherical coord's leads to the domain wall profile (Fig.2); a function of y and the domain wall width λ_B:

$$\theta = 2\arctan\left[\exp\left(\frac{y}{\lambda_B}\right)\right]$$

We **rotate the frame of reference**, as shown in Fig. 3, to follow the static magnetisation $\mathbf{M}_0$.

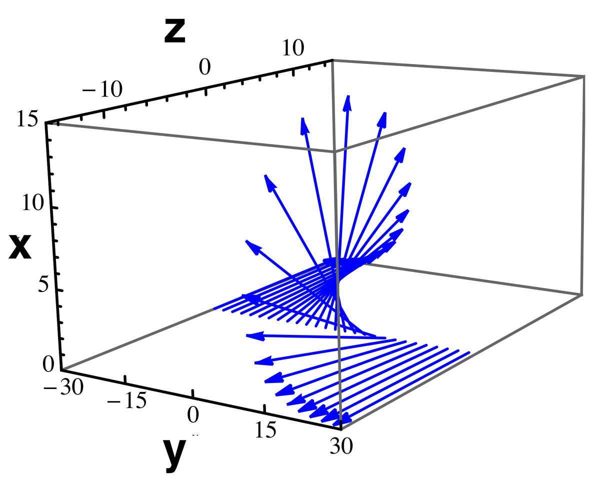


Fig.2: Static magnetisation $\mathbf{M}_0$ with $\lambda_B \approx$ 6nm. NB: The length of $\mathbf{M}_0$ is arbitrarily sized for clarity.

We then **linearise** the Landau-Lifshitz equation and solve for $\tilde{\mathbf{m}}'_{\beta}$; the excitation of magnetisation due to the domain wall.

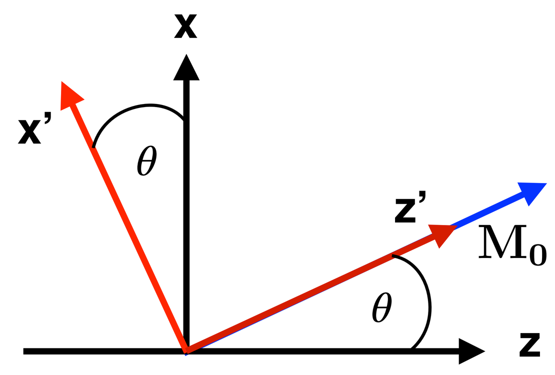
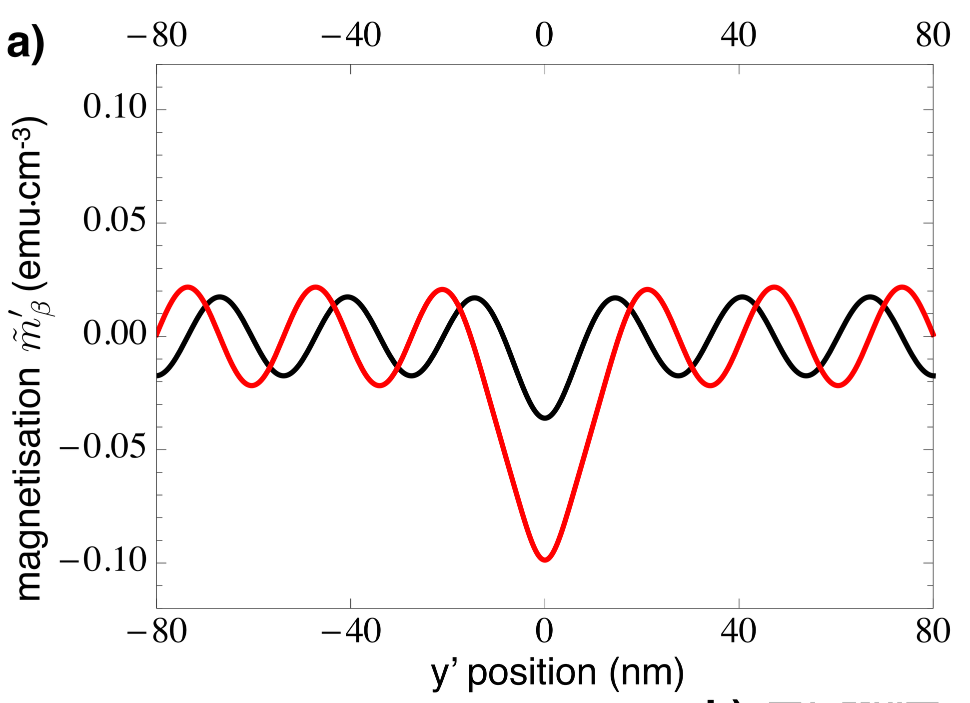


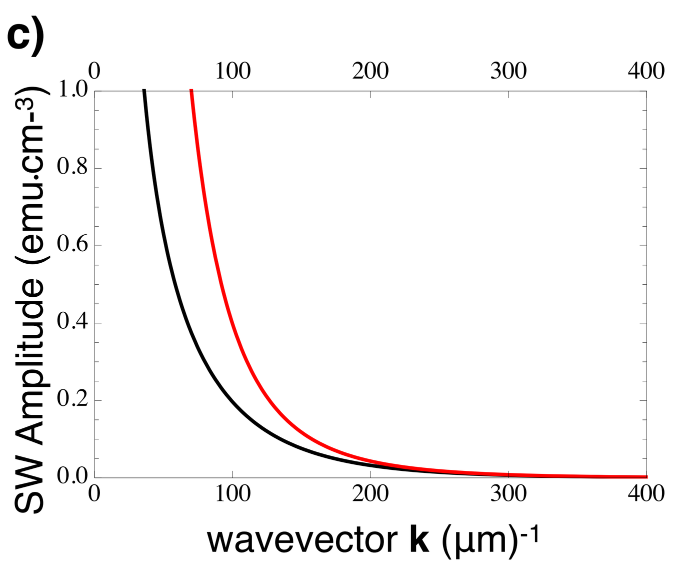
Fig.3: Rotated (primed) frame. The **z'** axis always follows $\mathbf{M}_0$, and **y = y'**.

Results & Discussion

- **SWs emitted** for frequency: $\omega > \gamma M_0\sqrt{\beta_{\parallel}(\beta_{\parallel}+\beta_{\perp})}$ (Fig.4a,4b).
- Amplitude and wavelength (Fig.4c) determined by $\mathbf{h}(t)$.



b)



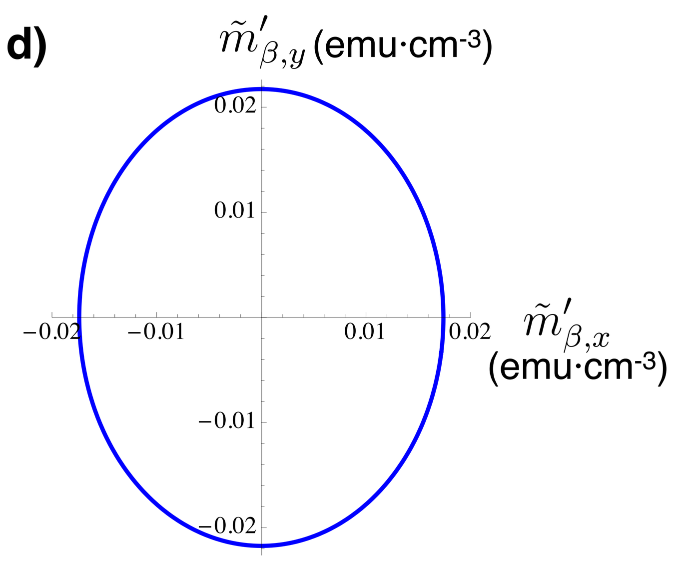


Fig.4
a) x' component (black) and y' component (red) of $\tilde{m}'_{\beta}$ vs. position y', **b)** Animation of a) for 1 period of oscillation, **c)** SW amplitude vs. wavevector **k**, **d)** Ellipticity of magnetisation at y=40nm.

*Values used: α=3.125×10-12cm2, γ=1.8×107(Oe·s)-1, M0=800emu·cm-3, |**h**(t)|=1Oe, $\beta_{\parallel}$=0.1, $\beta_{\perp}$=10, frequency=$\omega/2\pi$=50GHz.*

- SWs are **elliptical** (Fig.4d) with ellipticity reducing at large **k**.
- Magnetisation vectors in unprimed frame clearly show domain wall **oscillating** back and forth, causing SW emission (Fig.5).

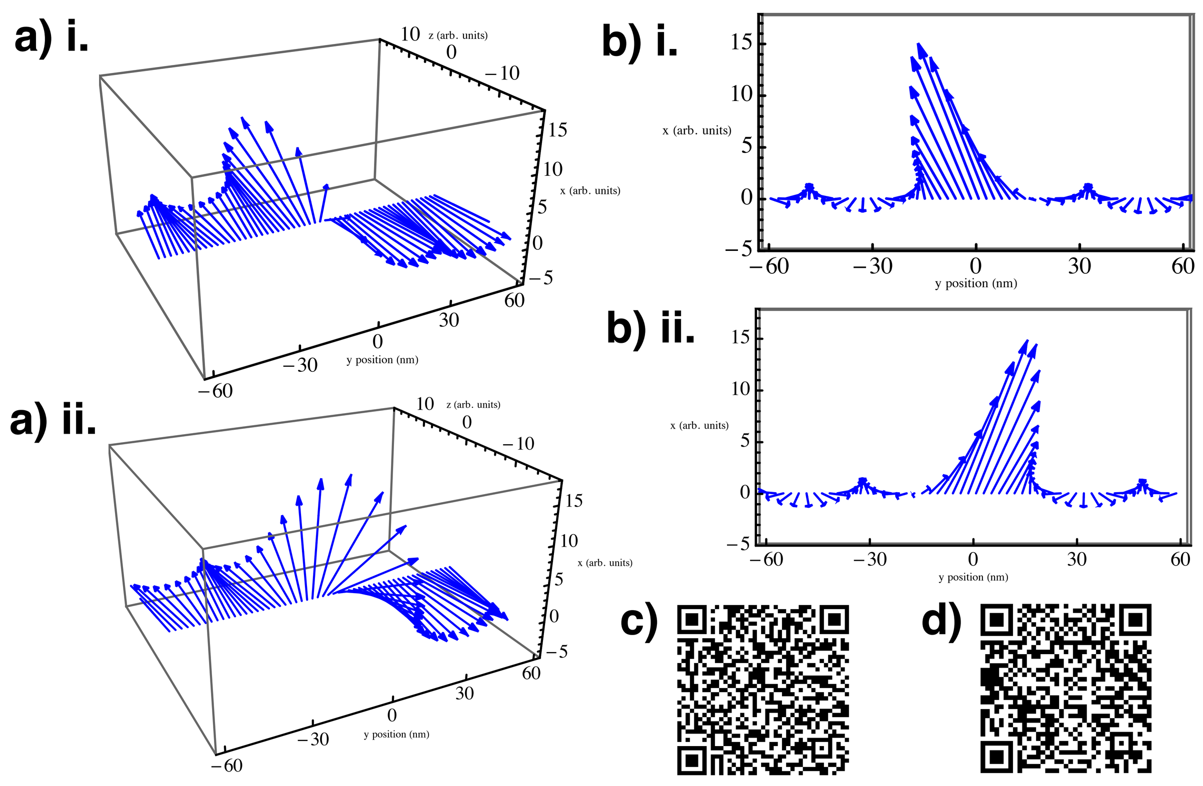


Fig.5
Magnetisation vectors in unprimed frame, with **a)** axonometric view and **b)** side view, both for **i.** phase = 0 and **ii.** phase = π. **c)** animation of a), and **d)** animation of b), both with phase varying from 0 to 2π. NB: all magnetisation lengths are arbitrary.

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